THE RELATIVE IMPORTANCE OF TERM SPREAD, POLICY INERTIA AND PERSISTENT POLICY SHOCKS IN ESTIMATED MONETARY POLICY RULES: A STRUCTURAL APPROACH *

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ABSTRACT

This paper estimates a standard version of the New Keynesian Monetary (NKM) model augmented with term structure in order to analyze two types of issue. First we analyze the relative importance of policy inertia, persistent policy shocks and the term spread in the estimated U.S. monetary policy rule. Second, we study the ability of the model to reproduce some stylized facts such as high persistent dynamics and the weak comovement between economic activity and inflation observed in actual U.S. data. The estimation procedure implemented is a classical structural method based on the indirect inference principle. The empirical results show that (i) policy inertia and persistent policy shocks are significant determinants in the estimated U.S. monetary policy rule; (ii) the Fed does not seem to respond independently to the spread; and (iii) the model augmented with term structure reproduces the weak comovement between economic activity and inflation as well as the strong comovement at medium- and long-term forecast horizons between the Fed rate and the 1-year rate observed in U.S. data.

1 INTRODUCTION

Many empirical studies (see for instance, Clarida, Galí and Gertler, 2000) have found that lagged interest rate is a key component in estimated policy rules. Two alternative interpretations have been proposed in the relevant literature. On the one hand, there are several arguments suggesting that the significant role of lagged interest rate may reflect the existence of an optimal policy inertia. These arguments range from the traditional concern of central banks for the stability of financial markets (see Goodfriend, 1991 and Sack, 1997) to the more psychological argument posed by Lowe and Ellis (1997) that there might be a political incentive for smoothing whenever policymakers are likely to be embarrassed by reversals in the direction of interest-rate changes if they believe that the public may interpret them as repudiations of previous actions. By contrast, a series of interest-rate changes in the same direction looks like a well-designed programme, and that may give rise to the sluggish behavior of the intervention interest rate. On the other hand, Rudebusch (2002) argues that the significance of the lagged interest rate in estimated policy rules is due to the existence of relevant omitted variables. The presence of omitted variables results in persistent monetary policy shocks in estimated policy rules. Rudebusch argues that it is hard to reconcile the lack of evidence on the predictive power of the term structure for future values of the short-term interest rate with the existence of policy inertia.

By using U.S. data and reduced-form econometric approaches, English, Nelson, and Sack (2003) and Gerlach-Kristen (2004) have recently estimated standard Taylor rules that allow for policy inertia and persistent policy shocks to reflect the possibility of unobservable variables.[1] The empirical results in the two papers show that policy inertia and persistence policy shocks are relevant features in the estimated policy rule. Moreover, Gerlach-Kristen (2004) finds that the term spread between a 10-year Treasury rate and a risky bond rate is also a significant determinant of the U.S. policy rule and its inclusion does not preclude policy inertia and persistent policy shocks from both featuring the policy rule.

The aim of this paper is twofold. First, we analyze the relative importance of policy inertia, term structure and persistent policy shocks in the

[1] We use the term "standard Taylor rule" to distinguish it from a forward-looking Taylor rule and from a backward-looking Taylor rule. Under a standard policy rule, the Fed rate responds to current deviations of inflation and ouput from their respective steady state values whereas under a forward-looking (backward-looking) Taylor rule, the Fed rate responds to expected (lagged) deviations of inflation and ouput from their respective steady state values.

characterization of the estimated U.S. monetary policy rule. We build upon the above literature by estimating a New-Keynesian Monetary (NKM) model augmented with term structure where the Fed funds rate and the 1-year Treasury constant maturity rate are considered. The second goal of the paper is to study the ability of the estimated NKM model augmented with term structure to reproduce two stylized facts: the weak comovement between output and inflation and the highly persistent dynamics exhibited by U.S. output, inflation and interest rate data.[2]

By considering an NKM model augmented with term structure, this paper is also related to a fast growing literature (such as Hördahl, Tristani and Vestin, 2004; Rudebusch and Wu, 2004; and Bekaert, Cho and Moreno, 2005) that aims to link the NKM model dynamics with term structure.[3] However, they differ from our paper on how term structure is introduced, on the focus of the paper and on the structural econometric approach followed. Rudebusch and Wu (2004) build upon a typical affine no-arbitrage term structure representation with two latent factors (level and slope) by linking, (admittedly) in an ad-hoc fashion, these two factors to macroeconomic variables (inflation and output gap) which are determined by an NKM model. In a similar vein and using little macroeconomic structure, Ang, Dong and Piazzesi (2005) consider a single latent factor interpreted as a transformation of Fed policy actions on the short rate. In their model, persistent policy shocks are allowed but policy inertia is not. Hördahl et al. (2004) and Bekaert et al. (2005) introduce term structure by assuming an affine term structure model derived from first principles where consumption growth is lognormally distributed. In contrast to these papers, our paper introduces term structure by simply considering a representative agent optimization problem allowing the agent to have access to bonds of different maturities and without assuming any explicit form for consumption growth.

Closely related to Rudebusch and Wu (2004) and Ang et al. (2005), the focus of our paper is to analyze whether term structure helps to characterize the policy rule whereas the main focus in Hördahl et al. (2004) and Bekaert et al. (2005) is to study how term structure is determined by macroeconomic factors in Germany and the U.S., respectively. Moreover, Hördahl et al. (2004) and Rudebusch and Wu (2004) use a maximum likelihood approach, Bekaert et al. (2005) use the generalized method of moments and Ang et al.

[2]See María-Dolores and Vázquez (2004) for an analysis of the comovement between output and inflation using alternative measures of economic activity and inflation and for references on a long standing debate on the relationship between output and prices.

[3]There are also many other papers (for instance, see Ang and Piazzesi, 2003; and Diebold, Rudebusch and Aruoba, 2003) linking macro variables to the yield curve using little or no macroeconomic structure.

(2005) implement a Bayesian estimation approach to estimate their macro-finance models of the term structure. We follow María-Dolores and Vázquez (2005) by considering (i) a structural econometric approach based on the *indirect inference* principle and (ii) three alternative specifications for the monetary policy rule called standard, forward-looking and backward-looking rule. In a standard three-variable NKM model, María-Dolores and Vázquez (2005) show that the estimates of some behavioral/structural parameters are largely sensitive to the specification of the policy rule assumed. This result is quite unpleasant since, by definition of structural parameters, one would want to get estimates for these parameters that were robust to alternative specifications of monetary policy.

Considering term structure in an otherwise standard NKM model introduces two types of feature. On the one hand, it introduces persistent effects through the IS equation, which are different for instance from the ones introduced by habit formation à la Furher (2000). On the other hand, it allows us to consider the term spread as an additional determinant in the structural estimation of the monetary policy rule and then to tackle the question of whether the Fed responds only to the information content of the spread about inflation and real activity or responds independently to the spread. The inclusion of the term spread in the monetary rule is motivated by the empirical evidence found by many researchers (among others, Fama, 1990, Mishkin, 1990, Estrella and Hardouvelis, 1991, and Estrella and Mishkin, 1997) that the term spread contains useful information concerning market expectations of both future real economic activity and inflation.[4]

The empirical results in this paper show that (i) a standard Taylor rule fits U.S. data better than a forward-looking rule or a backward-looking Taylor rule; and (ii) policy inertia and persistent policy shocks are significant features under the three specifications even when the term spread is included in the policy rule. The latter result is similar to that found by English et al. (2003) and Gerlach-Kristen (2004) considering a standard Taylor rule and a reduced-form estimation approach. In contrast to Gerlach-Kristen (2004), the coefficient associated with the term spread in the Taylor rule is not significant in most cases studied and much smaller than the one obtained by Gerlach-Kristen. The evidence of monetary policy inertia also contrasts to that found by Rudebusch and Wu (2004). Nevertheless, one must notice that our empirical results are similar to those found by Rudebusch and Wu

[4] The idea of including the term spread (or some other element related to the term structure) in the monetary rule is not new. For instance, following reduced-form estimation approaches, Carey (2001) includes a 10-year bond yield and Gerlach-Kristen (2004) includes the spread between a safe bond (the 10-year Treasury constant maturity rate) and a risky bond (the Moody's Baa corporate bond index).

(2004) in the sense that the relative importance of policy inertia decreases once persistent policy shocks are considered.

Moreover, the empirical results show that the term spread is significant under a backward-looking Taylor rule but not under a standard and a forward-looking rule. This empirical evidence suggests that the Fed may respond to the information content of the spread about current inflation and real activity, but the Fed does not seem to respond independently to the spread. Furthermore, the estimates of structural parameters in the NKM model augmented with term structure are stable across alternative specifications of the policy rule, in contrast to the results found by María-Dolores and Vázquez (2005) under the standard NKM model.

By using Den Haan's (2000) methodology to study the comovement between pairs of variables, the paper also shows that the NKM model augmented with term structure is capable of replicating the weak comovement between economic activity and inflation as well as the strong comovement between the Fed funds rate and the 1-year Treasury rate observed in U.S. data.

The rest of the paper is organized as follows. Section 2 introduces the log-linearized approximation of a standard version of the NKM augmented with term structure. Moreover, this section motivates the use of a structural econometric strategy to estimate monetary policy rules. Section 3 describes the structural estimation method used in this paper. Section 4 presents and discusses the estimation results. Section 5 provides diagnostic tests, impulse response and comovement analyses to identify features of the data that the NKM model augmented with term structure does (not) account for. Section 6 concludes.

2 A NEW KEYNESIAN MONETARY MODEL WITH TERM STRUCTURE

The model analyzed in this paper is a now-standard version of the NKM model augmented with term structure, which is given by the following set of equations:

$$y_t = E_t y_{t+j} - \tau(i_t^{\{j\}} - E_t \pi_{t+j}) + g_t^{\{j\}}, \text{ for } j = 1, ..., n \tag{1}$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + z_t, \tag{2}$$

$$i_t = \rho i_{t-1} + (1-\rho)[\psi_1 \pi_t + \psi_2 y_t + \psi_3 (i_{t-1}^{\{j\}} - i_{t-1}^{\{k\}})] + v_t. \tag{3}$$

where y, π and $i^{\{j\}}$ denote the log-deviations from the steady states of output, inflation and nominal interest rate associated with a j-period bond, respectively. E_t denotes the conditional expectation based on the agents' information set at time t. $g^{\{j\}}$, z and v denote aggregate demand, aggregate supply and monetary policy shocks, respectively. Each of these shocks is further assumed to follow a first-order autoregressive process

$$g_t^{\{j\}} = \rho_g^{\{j\}} g_{t-1}^{\{j\}} + \epsilon_{gt}^{\{j\}}, \text{ for } j = 1, ..., n \tag{4}$$

$$z_t = \rho_z z_{t-1} + \epsilon_{zt}, \tag{5}$$

$$v_t = \rho_v v_{t-1} + \epsilon_{vt}, \tag{6}$$

where $\epsilon_{gt}^{\{j\}}$, ϵ_{zt} and ϵ_{vt} denote i.i.d. random shocks. We further allow for correlation between $\epsilon_{gt}^{\{j\}}$ shocks.

Equations (1) are the log-linearized consumption first-order conditions obtained from the representative agent optimization plan. The parameter $\tau > 0$ represents the intertemporal elasticity of substitution obtained when assuming a standard constant relative risk aversion utility function.[5] Combining two IS equations, say j and l, one gets a highly persistent IS where expected realizations of output at different forecast horizons are linked to the ex-ante real interest rates associated with the alternative maturity bonds in the economy:

$$E_t y_{t+j} = E_t y_{t+l} - \tau[(i_t^{\{l\}} - E_t \pi_{t+l}) - (i_t^{\{j\}} - E_t \pi_{t+j})] + g_t^{\{l\}} - g_t^{\{j\}},$$

for $j = 1, ..., n$, and $j \neq l$. Without loss of generality we can assume that $l > j$. This equation can be further manipulated to obtain the following *intertemporal IS-equation:*

$$i_t^{\{l\}} - i_t^{\{j\}} = \frac{1}{\tau} E_t(y_{t+l} - y_{t+j}) + E_t(\pi_{t+l} - \pi_{t+j}) + \frac{1}{\tau}(g_t^{\{l\}} - g_t^{\{j\}}). \tag{7}$$

The *intertemporal IS-equation* structurally links the term spread associated with bonds of maturity l and j with the expected growth rate of output between periods $t + j$ and $t + l$ (weighted by the risk aversion parameter, $1/\tau$) and the expected change in the rate of inflation between periods $t + j$ and $t + l$.

Equation (2) is the new Phillips curve that is obtained in a sticky price à la Calvo (1983) model where monopolistically competitive firms produce (a

[5] Appendix 1 shows a detailed derivation of the j-IS curves, one IS curve for each j-period bond of the economy.

continuum of) differentiated goods and each firm faces a downward sloping demand curve for its produced good. The parameter $\beta \in (0,1)$ is the agent discount factor and κ measures the slope of the New Phillips curve.[6]

Equation (3) is a standard Taylor-type monetary rule where the nominal interest rate exhibits inertial behavior, captured by parameter ρ, for which there are several motivating arguments in the literature as those mentioned in the introduction. Moreover, the monetary policy rule (3) assumes that the nominal interest rate responds, on the one hand, to current deviations of output and inflation from their respective steady state values and, on the other hand, to lagged term spreads, $i_{t-1}^{\{j\}} - i_{t-1}^{\{k\}}$ for $j > k$.[7] Alternatively, we also consider a forward-looking Taylor rule

$$i_t = \rho i_{t-1} + (1-\rho)[\psi_1 E_t \pi_{t+1} + \psi_2 E_t y_{t+1} + \psi_3 (i_{t-1}^{\{j\}} - i_{t-1}^{\{k\}})] + v_t, \qquad (8)$$

and a backward-looking Taylor rule

$$i_t = \rho i_{t-1} + (1-\rho)[\psi_1 \pi_{t-1} + \psi_2 y_{t-1} + \psi_3 (i_{t-1}^{\{j\}} - i_{t-1}^{\{k\}})] + v_t. \qquad (9)$$

By considering alternative policy rule specifications, the term spread in the estimated policy rule and a structural estimation procedure, we expect to shed light on two relevant questions: (i) does the Fed respond only to the information content of the spread about future inflation and real activity, or does it respond independently to the spread?; and (ii) are the deep structural parameter estimates stable across alternative policy rule specifications.

Equation (7) shows that term spreads are endogenous and that term spreads and expected output and inflation paths are linked to IS-shocks. Therefore, estimating single-equation policy rules by ordinary least squares is not appropriate because regressors are endogenous. Moreover, when IS-shocks and policy shocks are highly persistent (as widely reported in the literature) is difficult to find appropriate instrumental variables to control for regressors endogeneity. These results further motivate the use of a structural estimation approach. As clearly stated by Lubik and Schorfheide (2005), structural (system-based) estimation methods correct for the endogeneity by taking into account the non-zero conditional expectation of structural and policy shocks.

The use of a structural econometric strategy to estimate monetary policy rules can be further motivated as follows. As pointed out by Clarida, Galí

[6] See, for instance, Galí (2002) for a detailed analytical derivation of the New Phillips curve.

[7] In the empirical analysis below, we also consider the case where current spread enters in the policy rule.

and Gertler (1999), the forward-looking Taylor rule can be solved (numerically) in order to get a reduced-form for the interest rate in terms of predetermined variables. This reduced-form looks like standard and backward-looking Taylor rules, but the difference is that the coefficients associated with the reduced-form of the forward-looking rule are cumbersome functions linking structural and policy parameters. More precise, the reduced-form coefficients associated with the forward-looking rule must satisfy a set of cross-equation restrictions imposed by the rational expectations assumption. Therefore, alternative policy rules are not likely to be statistically identical and a system-based econometric strategy is then required to discriminate between alternative monetary policy rules.

Since the structural econometric approach implemented is computationally quite demanding, we consider an economy with only two bonds: a 4-period bond as the long-term bond and a 1-period bond as the short-term bond.[8] Equations (1)-(6) can then be written as

$$y_t = E_t y_{t+4} - \tau(i_t^{\{4\}} - E_t \pi_{t+4}) + g_t^{\{4\}},$$

$$y_t = E_t y_{t+1} - \tau(i_t - E_t \pi_{t+1}) + g_t,$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + z_t,$$

$$\begin{aligned} i_t = \rho i_{t-1} + (1-\rho)[\psi_1 \pi_t + \psi_2 y_t + \psi_3 (i_{t-1}^{\{4\}} - i_{t-1})] + v_t, \\ g_t = \rho_g g_{t-1} + \epsilon_{gt}, \\ z_t = \rho_z z_{t-1} + \epsilon_{zt}, \\ g_t^{\{4\}} = \rho_g^{\{4\}} g_{t-1}^{\{4\}} + \epsilon_{gt}^{\{4\}}, \\ v_t = \rho_v v_{t-1} + \epsilon_{vt}, \end{aligned}$$

where for the sake of simplicity we further assume that the 1-period bond and the policy interest rate are the same.[9]

[8] We also try to consider the 10-year Treasury rate instead of the 1-year rate to ease comparison with Gerlach-Kristen (2004) results. However, the GAUSS programs we use to solve the NKM model augmented with term structure break down since the sizes of matrices Γ_0, Γ_1, Π and Ψ defined below are too large. For instance, Γ_0 and Γ_1 are 88×88 matrices.

[9] This assumption is not very harmful when using quarterly data since the 3-month T-bill rate dynamics are similar to the Fed rate dynamics, which is the short-term rate used by the Fed to monitor monetary policy. More precise, the sample correlation between these two interest rates is 0.994 during the Greenspan era. In order to save notation, we have further removed the supersript associated with the 1-period interest rate, shock and shock parameter, respectively.

These eight equations (together with eight extra identities involving forecast errors) can be written in matrix form as follows

$$\Gamma_0 \xi_t = \Gamma_1 \xi_{t-1} + \Psi \epsilon_t + \Pi \eta_t, \tag{10}$$

where[10]

$$\xi_t = (y_t, \pi_t, i_t, i_t^{\{4\}}, E_t y_{t+1}, E_t y_{t+2}, E_t y_{t+3}, E_t y_{t+4}, E_t \pi_{t+1}, E_t \pi_{t+2}, E_t \pi_{t+3}, E_t \pi_{t+4}, g_t, z_t, g_t^{\{4\}}, v_t)'$$

$$\epsilon_t = (\epsilon_{gt}, \epsilon_{zt}, \epsilon_{gt}^{\{4\}}, \epsilon_{vt})',$$

$$\begin{aligned} \eta_t \;=\; & (y_t - E_{t-1}[y_t], E_t[y_{t+1}] - E_{t-1}[y_{t+1}], E_t[y_{t+2}] - E_{t-1}[y_{t+2}], E_t[y_{t+3}] - E_{t-1}[y_{t+3}], \\ & \pi_t - E_{t-1}[\pi_t], E_t[\pi_{t+1}] - E_{t-1}[\pi_{t+1}], E_t[\pi_{t+2}] - E_{t-1}[\pi_{t+2}], E_t[\pi_{t+3}] - E_{t-1}[\pi_{t+3}])' \end{aligned}$$

Equation (10) represents a linear rational expectations (LRE) system. It is well known that LRE systems deliver multiple stable equilibrium solutions for certain parameter values. Lubik and Schorfheide (2003) characterize the complete set of LRE models with indeterminacies and provide a numerical method for computing them that builds on Sims' (2002) approach.[11] In this paper, we deal only with sunspot-free equilibria.[12]

3 ESTIMATION PROCEDURE

In order to estimate the structural and policy parameters of the NKM model with term structure, we follow the *indirect inference* principle proposed by Gouriéroux, Monfort and Renault (1993), Smith (1993), and Gallant and Tauchen (1996). A VAR representation is considered as the auxiliary model. More precisely, we first estimate a four-variable VAR with four lags in order to summarize the joint dynamics exhibited by U.S. quarterly data on

[10] Appendix 2 displays the matrices Γ_0, Γ_1, Ψ and Π.

[11] The GAUSS code for computing equilibria of LRE models can be found on Frank Schorfheide's website.

[12] Lubik and Schorfheide (2003) deal with multiple equilibria by assuming that agents observe an exogenous sunspot shock ζ_t, in addition to the fundamental shocks, ϵ_t. Since an LRE system such as (10) is linear, the forecast errors, η_t, can be expressed as a linear function of ϵ_t and $\zeta_t : \eta_t = A_1 \epsilon_t + A_2 \zeta_t$, where A_1 is 2×3 and A_2 is 2×1 in this model. There are three possible scenarios: (i) no stable equilibrium; (ii) a unique stable equilibrium in which A_1 is completely determined by the structural parameters of the model and $A_2 = 0$; and (iii) multiple stable equilibria in which A_1 is not uniquely determined by the structural parameters of the model and A_2 can be non-zero. In this last case, one can deal only with a stable sunspot-free equilibrium by imposing $A_2 = 0$ and then the corresponding equilibrium can be understood as a sunspot equilibrium with no sunspots.

output gap, inflation, Fed funds rate and 1-year Treasury constant maturity rate. Second, we apply the simulated moments estimator (SME) suggested by Lee and Ingram (1991) and Duffie and Singleton (1993) to estimate the underlying structural and policy parameters of the NKM model.[13]

This estimation strategy is especially appropriate in this context for three main reasons.[14] First, the NKM model is a highly stylized model of a complex world and this model will be rejected with probability one when a test with sufficient power is used. Therefore, maximum-likelihood estimation of the restricted VAR model implied by the NKM model may not be appropriate. In the words of Cochrane (2001, p. 293) "[*maximum likelihood*] *does the "right" efficient thing if the model is true. It does not necessarily do the "reasonable" thing for "approximate" models.*" Second, macroeconomic variables such as output gap, inflation and interest rates show a great deal of persistence. Since VAR's are well suited to deal with persistence an unrestricted VAR is a good candidate as the auxiliary model in this context. Finally, the VAR auxiliary model nests the NKM model with term structure considered. As shown by Gallant and Tauchen (1996), if the auxiliary model nests the structural model then the estimator is as efficient as maximum likelihood. Moreover, the estimation approach based on the indirect inference principle may help to identify which structural parameter estimates are forced to go outside of the economically reasonable support (for instance, the prior distribution support used by Bayesian estimator applications) in order to achieve a better fit of the NKM model.

The SME makes use of a set of statistics computed from the data set used and from a number of different simulated data sets generated by the model being estimated. More specifically, the statistics used to carry out the SME are the coefficients of the four-variable VAR with four lags, which is considered as the auxiliary model in this paper. The lag length considered is fairly reasonable when using quarterly data. To implement the method, we construct a $p \times 1$ vector with the coefficients of the VAR representation obtained from actual data, denoted by $H_T(\theta_0)$, where p in this application is 78,[15] T denotes the length of the time series data, and θ is a $k \times 1$ vector whose com-

[13] In this vein, Amato and Laubach (2003) and Boivin and Giannoni (2003) use a minimum distance estimator based on the impulse-response functions instead of VAR coefficients. See Gutiérrez and Vázquez (2004) and Ruge-Murcia (2003) for other recent applications of this estimation strategy based on VAR coefficients.

[14] At this point, the reader may have the following three questions in mind. Why do we not estimate the NKM model by maximun-likelihood directly? Why do we use a VAR as the auxiliary model? What do we learn from the estimation of the NKM model based on the indirect inference principle? This paragraph answers these three questions.

[15] We have 68 coefficients from a four-lag, four-variable system and 10 extra coefficients from the non-redundant elements of the variance-covariance matrix of the VAR residuals.

ponents are the model parameters. The true parameter values are denoted by θ_0. In the NKM model with term structure, the structural and policy parameters are $\theta = (\tau, \beta, \rho, \kappa, \psi_1, \psi_2, \psi_3, \rho_g, \rho_g^{\{4\}}, \rho_z, \rho_v, \rho_{gg}, \sigma_g, \sigma_g^{\{4\}}, \sigma_z, \sigma_\varepsilon, \pi^*)$ and then $k = 17$. ρ_{gg} denotes the correlation between ϵ_{gt} and $\epsilon_{gt}^{\{4\}}$ shocks.[16]

Given that the real data are by assumption a realization of a stochastic process, the randomness in the estimator can be decreased by simulating the model m times. For each simulation a $p \times 1$ vector of VAR coefficients, denoted by $H_{N,i}(\theta)$, is obtained from the simulated time series of output gap, inflation and interest rate generated from the NKM model, where $N = nT$ is the length of the simulated data. Averaging the m realizations of the simulated coefficients, i.e. $H_N(\theta) = \frac{1}{m}\sum_{i=1}^{m} H_{Ni}(\theta)$, we obtain a measure of the expected value of these coefficients, $E(H_{Ni}(\theta))$. To generate simulated values of output gap, inflation and interest rate we need the starting values of these variables. For the SME to be consistent, the initial values must have been drawn from a stationary distribution. In practice, to avoid the influence of the starting values we follow Lee and Ingram's suggestion of generating a realization from the stochastic processes of the four variables of length $2N$, discard the first N-simulated observations, and use only the remaining N observations to carry out the estimation. After N observations have been simulated, the influence of the initial conditions must have disappeared.

The choice of values for n and m deserves some attention. Gouriéroux, Renault and Touzi (2000) suggests that is important that the sample size of synthetic data would be identical to T (that is, $n = 1$) in order to get identical size of finite sample bias in estimators of the auxiliary parameters computed from actual and synthetic data. On the contrary, most indirect inference applications (for instance, Smith, 1993; Ruge-Murcia, 2003; Gutiérrez and Vázquez, 2004) consider N larger than T (that is, $n = 5, 10, 20$) because a large N is important to estimate persistent dynamic process. We make $n = m = 10$ in this application, but we check for robustness of the empirical results by also considering $n = 1$ and $m = 100, 500$.

The SME of θ_0 is obtained from the minimization of a distance function of VAR coefficients from real and simulated data. Formally,

$$\min_{\theta}\ J_T = [H_T(\theta_0) - H_N(\theta)]' W [H_T(\theta_0) - H_N(\theta)],$$

where the weighting matrix W^{-1} is the covariance matrix of $H_T(\theta_0)$.

Denoting the solution of the minimization problem by $\hat{\theta}$, Lee and Ingram

[16] We have also allowed for correlation between ϵ_{gt}'s shocks and ϵ_{zt}, but the correlation parameter turns out to be non-significant.

(1991) and Duffie and Singleton (1993) prove the following results:

$$\sqrt{T}(\hat{\theta}-\theta_0) \rightarrow N\left[0, \left(1+\frac{1}{m}\right)(B'WB)^{-1}\right],$$

$$\left(1+\frac{1}{m}\right) TJ_T \rightarrow \chi^2(p-k),$$

where B is a full rank matrix given by $B = E(\frac{\partial H_{Ni}(\theta)}{\partial\theta})$.[17]

The estimation approach followed in this paper is similar to the one followed by Rotemberg and Woodford (1997). They estimate an NKM model by minimizing a distance function between the impulse response functions obtained from actual data and those derived from synthetic data (i.e., data generated by the model).[18] As in Rotemberg and Woodford (1997), our estimation procedure uses a VAR as the auxiliary model, but the distance function is built upon the coefficients estimated from an unrestricted VAR instead of upon the impulse response functions. We pay attention to the VAR coefficients for two main reasons. First, obtaining *sensible* impulse response functions usually requires the inclusion of additional variables. For instance, to solve the so called *price puzzle* a commodity price index is included in the impulse response analysis even though the NKM model is silent about how the commodity price index is determined. Second, applications of the minimum distance estimator based on impulse response functions use a diagonal weighting matrix that includes the inverse of each impulse response's variance on the main diagonal. This weighting matrix delivers consistent estimates of the structural parameters, but it is not asymptotically efficient since it does not take into account the whole covariance matrix structure associated with the set of moments.[19] By considering the VAR coefficients as the set of moments in order to implement the minimum distance estimator, an estimator of the efficient weighting matrix is found to be straightforward.[20]

[17] The objective function J_T is minimized using the optimization package OPTMUM programmed in GAUSS language. The Broyden-Fletcher-Glodfard-Shanno algorithm is applied. To compute the covariance matrix we need to obtain B. Computation of B requires two steps: first, obtaining the numerical first derivatives of the coefficients of the VAR representation with respect to the estimates of the structural parameters θ for each of the m simulations; second, averaging the m-numerical first derivatives to get B. The GAUSS programs for estimating the NKM model augmented with term structure are available from the authors upon request.

[18] A similar approach is followed by Amato and Laubach (2003) and Boivin and Giannoni (2003)

[19] Boivin and Giannoni (2003) indicate this drawback, but provide no alternative.

[20] See Duffie and Singleton (1993, p.939) for a discussion on the choice of a weighting matrix in order to obtain asymptotic efficient estimates.

4 EMPIRICAL EVIDENCE

4.1 The data

We consider quarterly U.S. data for the output gap, the inflation rate obtained for the implicit GDP deflator, the Fed funds rate and the 1-year Treasury constant maturity rate during the Greenspan era.[21] We focus on the Greenspan period for several reasons. First, it allows a more straightforward comparison of the estimated monetary policy rules of English et al. (2003), Gerlach-Kristen (2004), and Rudebusch and Wu (2004). Second, the Taylor rule seems to fit better in this period than in the pre-Greenspan era. Third, considering the pre-Greenspan era opens the door to many issues studied in the literature, including the presence of macroeconomic switching regimes and the existence of switches in monetary policy (Sims and Zha, 2004, Cogley and Sargent, 2001, and Canova, 2004) and the presence of multiple equilibria and indeterminacy (Lubik and Schorfheide, 2004). These issues are beyond the scope of this paper. Figure 1 shows the four time series.

4.2 Estimation results

Tables 1-3 show the estimation results under the standard, forward-looking and backward-looking Taylor rules, respectively. In each table, the estimation results for four cases are displayed. The second column shows the estimates for the model without restrictions. The third column shows the estimates imposing the restriction that the term spread does not enter into the policy rule ($\psi_3 = 0$). The fourth column displays the estimates obtained when we do not allow for persistent monetary policy shocks ($\rho_v = 0$). Finally, the fifth column shows the estimates when the current term spread enters into the policy rule instead of the lagged term spread. The values of the goodness-of-fit statistic, $\left(1+\frac{1}{n}\right) TJ_T$,which is distributed as a $\chi^2(p-k)$,[22] confirm the hypothesis stated above that the NKM model augmented with term structure under any specification considered is still too stylized to be supported by actual data. The best fit is obtained under a standard Taylor

[21] U.S. output gap is measured as the percentage deviation of GDP from the real potential GDP time series constructed by the U.S. Congressional Budget Office. Appendix 3 describes the data sources.

[22] For the NKM model without imposing any restriction the goodness-of-fit statistic is distributed as a $\chi^2(61)$ since the number of VAR coefficients is $p = 78$ and the number of parameters being estimated is $k = 17$.

rule that includes the lagged term spread without imposing any restriction (Table 1, second column). We observe that the coefficients associated with the term spread (ψ_3), policy inertia (ρ) and the persistency of policy shocks (ρ_v) are all significant at any standard significance level.[23]

Following Gourieroux et al. (2000) suggestion, we study the robustness of the empirical results by re-estimating the model for $n = 1$ and $m = 100, 500$. For the sake of brevity, we only display the estimation results for $n = 1$ and $m = 100$ in Table 4. Comparing Table 4 columns with their counterparts in Tables 1-3, we observe that the empirical results are robust to the choice of n and m. The only exception is the lack of significance of the term spread coefficient in the standard Taylor rule under $n = 1$ and $m = 100$.

Interestingly, looking at Tables 1-4 we observe that the estimates of structural parameters in the NKM model augmented with term structure are robust to alternative specifications of the policy rule in contrast to the highly sensitive estimates of τ and κ found by María-Dolores and Vázquez (2005) when considering a standard NKM model without term structure. Moreover, all parameters measuring shock persistence are significantly different from one, in contrast to the empirical results of María-Dolores and Vázquez (2005) where the random walk hypothesis for the IS shock is not rejected by the data.

The fact that the term spread is significant under a backward-looking Taylor rule but not under a standard and a forward-looking rule suggests that the Fed may respond to the information content of the spread about current inflation and real activity, but does not seem to respond independently to the spread.

Based on a structural estimation approach, our empirical results then confirm qualitatively the reduced-form estimation results obtained by English et al. (2003) and Gerlach-Kristen (2004) that policy inertia and persistent policy shocks play a role in the U.S. estimated policy rule. The evidence of monetary policy inertia challenges the empirical results found by Rudebusch and Wu (2004). Nevertheless, one must notice that our empirical results are consistent with those found by Rudebusch and Wu (2004) in a particular sense: the importance of policy inertia decreases once persistent policy shocks are considered (that is, when ρ_v is not restricted to be zero). Moreover, the point estimate of ρ_v (≈ 0.35) is much smaller than the estimate reported by Rudebusch and Wu (2004) ($\rho_u = 0.975$ in their notation). The empirical results also suggest that the importance of persistent policy shocks (probably

[23]Moreover, Wald tests based on the values of the goodness-of-fit statistic provide extra support that the term spread and persistent policy shocks are features characterizing the estimated monetary policy rule.

due to an omitted explanatory variable problem), measured by ρ_v, is reduced (but still remains significant) by considering the term spread in the policy rule.

Our results do not fully support the finding of Gerlach-Kristen (2004) that the term spread is also a determinant of the estimated policy rule. The different results may be due to the different long-term interest rate used. Gerlach-Kristen (2004) considers the 10-year maturity rate which may contain additional information (not included in the 1-year rate) for characterizing Fed rate movements. However, the large sample correlation (0.86) between the 1-year and the 10-year rate suggests that the former explanation is not good enough and that the different results on the term spread significance are possibly due to the alternative econometric strategies implemented in the two papers. As emphasized in Section 2, we believe that a system-based econometric approach deals better with endogeneity problems than a single-equation econometric strategy.

5 Model performance

Based on the J-Wald test, we have concluded above that the overall performance of the NKM model augmented with term structure is not good. This result does not mean that the model fails in all interesting dimensions. In this section, we consider diagnostic tests, impulse response analysis and comovement analysis to identify features of the data that the NKM model augmented with term structure does (not) account for.[24]

5.1 Diagnostic tests

Since the VAR residuals are orthogonal to the VAR dependent variables, the goodness-of-fit statistic can be decomposed into two terms: $J_T(\theta) = J_T^1(\theta) + J_T^2(\theta)$, where $J_T^1(\theta)$ measures the distance associated with the systematic part of the VAR and $J_T^2(\theta)$ measures the distance associated with the coefficients of the variance-covariance matrix of the VAR residuals. The estimation results obtained with the NKM model augmented with term structure under the standard Taylor rule results in $J_T^1(\theta) = 1.8425$ and $J_T^2(\theta) = 0.7534$.

[24] The empirical results reported in this section are based on $n = m = 10$. Similar results are found with $n = 1$ and $m = 100, 500$.

Therefore, the model has more trouble in accounting for the non-systematic part than for the systematic part of the VAR.[25]

The components of the vector $[H_T(\theta_0) - H_N(\theta)]$ contain information on how well the NKM model augmented with term structure accounts for the estimates of the VAR (auxiliary) model. Larger components point to the estimates of the auxiliary model that the NKM model augmented with term structure has trouble accounting for. As suggested by Gallant, Hsieh and Tauchen (1997) the following quasi-t-ratios statistics can identify sources for model failure:

$$\sqrt{1+\frac{1}{n}}\sqrt{T}\left[\left(diag(W_T^{-1})\right)_i^{1/2}\right]^{-1}[H_T(\theta_0) - H_N(\theta)]_i \quad \text{for} \qquad i = 1, ..., p, \tag{11}$$

where W_T is a consistent estimate of W, $\left(diag(W_T^{-1})\right)_i$ denotes the i-th element of the diagonal of matrix W_T^{-1} and $[H_T(\theta_0) - H_N(\theta)]_i$ is the i-th element of $[H_T(\theta_0) - H_N(\theta)]$. In particular, a large i-th diagnostic statistic indicates that the NKM model does a poor job of fitting the i-th coefficient of the VAR model.

The second and third columns in Table 5 show the VAR estimates and the corresponding standard errors, respectively. The remaining columns in Table 5 show the corresponding quasi-t-ratio diagnostic statistic (11) for the alternative policy rules studied. Looking at the fourth column in Table 5, we observe that the NKM model augmented with term structure under the standard Taylor rule has trouble in accounting for output gap, inflation, Fed rate and 1-year rate persistence since for each equation some dependent variable lags are significant and the associated diagnostic statistic is large. These results are robust to alternative specifications of the monetary policy rule.

5.2 Impulse response analysis

Figures 2-4 show the impulse response of output gap, inflation, short-term rate and long-term rate to a monetary policy shock, an aggregate supply (AS) shock and an aggregate demand (AD) shock, respectively. In these figures, the solid line represents the impulse response implied by the model whereas the dashed lines are 95% confidence bands. The size of the shock is determined by its estimated standard deviation.

[25] Notice that $J_T^1(\theta)$ is computed based on 68 coefficients whereas $J_T^2(\theta)$ is based on 10. Our conclusion is then based on the fact that the ratio 68/10 is almost three times larger than $J_T^1(\theta)/J_T^2(\theta) = 2.45$.

Figure 2 shows that a contractionary monetary policy shock reduces output in the short-run, but output recovers rapidly (five quarters). A contractionary monetary policy shock has significant positive (negative) effects on interest rates (inflation) and only in the short-run. Figure 3 shows that a contractionary AS shock reduces output and increases inflation in the short-run. After the short-run impact, output slowly increases during the transition to the steady state whereas inflation falls below and then smoothly increases towards the steady state. The impulse response patterns of short and long-term interest rates are similar to that displayed by inflation. Figure 4 shows that a positive AD shock increases output, inflation and interest rates, but the effects last for only a few periods and are barely significant.

5.3 Comovement analysis

There is a long standing debate on the relationship between economic activity and prices (inflation). For a long time economists widely accepted that output and inflation displayed a positive correlation at least in the short-run. For a large group of economists, the positive short-run correlation between output and inflation (the so-called Phillips curve phenomenon) is still considered a necessary building block of business cycle theory (for instance, Mankiw, 2001). Yet this view is rather controversial in the literature. For instance, Kydland and Prescott (1990) argue that "*any theory in which procyclical prices figure crucially in accounting for postwar business cycle fluctuations is doomed to failure.*" Moreover, Cooley and Ohanian (1991) find evidence that the U.S. correlation between output and prices is negative during the postwar period.

Den Haan (2000) argues that an important source of disagreement in this literature is the focus on only the unconditional correlation coefficient. Den Haan proposes using correlations of VAR forecast errors at different horizons to analyze the comovement between pairs of variables. As discussed by Den Haan (2000), this methodology has two main advantages. First, variables need not be stationary for their comovement to be analyzed, so previous filtering is not required. Second, it avoids the type of *ad-hoc* assumptions necessary to compute impulse response functions. Since the comovement between a pair of variables is an equilibrium outcome (that is, an outcome resulting from the interaction between supply and demand shocks that is observed in the data without the need of any identifying assumption) comovement dynamics are good 'stylized' facts for analyzing a model's performance.

In this subsection, we apply the methodology suggested by Den Haan to study the comovement between (i) the level of economic activity measured by the output gap and inflation; and (ii) the Fed funds rate and the 1-year rate. The goal is to analyze the ability of the NKM model augmented with term structure to replicate the type of comovement between pairs of variables observed in U.S. data. Recently, María-Dolores and Vázquez (2004) have shown the presence of a weak comovement between economic activity and inflation in U.S. data using a wide range of alternative measures of economic activity and inflation.

Figures 5 and 6 show the comovement between output gap and inflation and between the Fed funds rate and the 1-year rate, respectively.[26] In each figure, the solid line represents the estimated correlations at different forecast horizons using U.S.data, the lines with long-dashes are 95% confidence bands computed using bootstrap methods and the line with short-dashes are the correlation coefficients implied by the model. Figure 5 shows (i) the presence of a weak comovement between output and inflation in the U.S.; and (ii) the NKM model with term structure is able to mimic the weak negative comovement between output and inflation in the short-run (up to two quarters forecast horizons) and a non-significant comovement at longer forecast horizons.

Figure 6 shows a weak positive comovement between the two interest rates at short-run forecast horizons whereas a strong positive comovement is present at medium- and long-run forecast horizons. Moreover, Figure 6 shows that the NKM model with term structure generates a negative comovement between interest rates in the short-run in contrast to the weak comovement exhibited by interest rate data. However, the model is able to reproduce the strong comovement between the two interest rates at medium- and long-run forecast horizons observed in U.S. data.

6 CONCLUSIONS

This paper follows a structural approach to analyze the relative importance of policy inertia, term structure and persistent monetary policy shocks in the characterization of the estimated U.S. monetary policy rule. The framework considered is an NKM model augmented with term structure where the monetary policy rule is one of the building blocks. A structural econometric approach based on the *indirect inference* principle is implemented. In order to study the robustness of the empirical results, three alternative specifications for the monetary policy rule are considered, called the standard rule, forward-looking rule and backward-looking rule.

[26] See Den Haan (2000) for details on this methology for analyzing comovement.

The paper also investigates the ability of the NKM model augmented with term structure to reproduce two features observed in U.S. data, namely the weak comovement between economic activity and inflation and the highly persistent dynamics exhibited by output, inflation and interest rates.

The empirical results show that a standard Taylor rule fits U.S. data better than a forward-looking or a backward-looking Taylor rule. Moreover, policy inertia and persistent policy shocks are still significant factors under the three specifications even when the term spread is included in the policy rule. The latter result is similar to that found by English et al. (2003) and Gerlach-Kristen (2004) considering a standard Taylor rule and a reduced-form estimation approach. In contrast to Gerlach-Kristen (2004), the coefficient associated with the term spread in the policy rule is not significant in most cases and always much smaller than that obtained by Gerlach-Kristen. The empirical evidence also suggests that the Fed may respond to the information content of the spread about current inflation and real activity, but it does not seem to respond independently to the spread.

Furthermore, the estimates of structural parameters in the NKM model augmented with term structure are robust to alternative specifications of the policy rule, in sharp contrast to the results found by María-Dolores and Vázquez (2005) under the standard NKM model. Finally, we show that the NKM model augmented with term structure is able to mimic the weak comovement between output and inflation as well as the strong comovement at medium- and long-term forecast horizons between the Fed funds rate and the 1-year rate observed in actual data. However, diagnostic tests also show that the model fails to reproduce the highly persistent dynamics characterizing U.S. output gap, inflation and interest rate time series.

Our empirical results should be interpreted with caution since the structural NKM model, as any dynamic stochastic general equilibrium model, is likely to be misspecified in several dimensions. As is well known (see, for instance, Lubik and Schorfheide, 2005), overall model specification is important since it may lead to biased estimates, prevent identification of the true structural parameters and may affect model selection. In despite of these warnings, the estimation of an NKM augmented with term structure looks like the most reasonable starting point to analyze empirically the interaction between macroeconomic variables and term structure.

APPENDIX 1

This appendix derives the set of IS equations (1). Consider that the representative consumer solves the problem of maximizing

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t)$$

subject to the condition that

$$C_t + \sum_{j=1}^{n} B_t^{\{j\}} \leq Y_t + \sum_{j=1}^{n} B_{t-j}^{\{j\}} R_{t-j}^{\{j\}},$$

where C, Y, $B^{\{j\}}$, $R^{\{j\}}$ denote consumption, income, stock of j-period bonds and gross real return of j-period bond, respectively. Under fairly general conditions this problem has a solution with a finite value of the objective function. The first-order necessary conditions are given by

$$U'(C_t) = \lambda_t,$$

$$\beta^j E_t(\lambda_{t+j} R_t^{\{j\}}) = \lambda_t, \text{ for } j = 1, ..., n$$

where $\{\lambda_t\}$ is a sequence of Lagrange multipliers. Substituting the first equation into each of the j-conditions gives

$$E_t \left[\beta^j \frac{U'(C_{t+j})}{U'(C_t)} R_t^{\{j\}} \right] = 1, \text{ for } j = 1, ..., n$$

Assuming (i) a standard constant relative risk aversion utility function and (ii) no physical capital, it is straightforward to log-linearize these Euler equations in order to obtain (1).

APPENDIX 2

This appendix shows the matrices involved in equation (10).

$$
\Gamma_0 = \begin{pmatrix}
1 & 0 & 0 & \tau & 0 & 0 & 0 & -1 & 0 & 0 & 0 & -\tau & 0 & 0 & -1 & 0 \\
1 & 0 & \tau & 0 & -1 & 0 & 0 & 0 & -\tau & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\
-\kappa & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
-(1-\rho)\psi_2 & -(1-\rho)\psi_1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{pmatrix},
$$

$$
\Gamma_1 = \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \rho-(1-\rho)\psi_3 & (1-\rho)\psi_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_g & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_z & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_g^{\{4\}} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_v \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0
\end{pmatrix},
$$

$$\Pi = \begin{pmatrix} 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 1&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0\\ 0&0&0&1&0&0&0&0\\ 0&0&0&0&1&0&0&0\\ 0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&1 \end{pmatrix},$$

$$\Psi = \begin{pmatrix} 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 1&0&0&0\\ 0&1&0&0\\ 0&0&1&0\\ 0&0&0&1\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0 \end{pmatrix}.$$

APPENDIX 3

This appendix describes the time series considered.

Economic activity indexes:

- GDP: quarterly, seasonally adjusted data. Period: 1987:3-2004:3. Source: U.S. Department of Commerce, Bureau of Economic Analysis.
- Real potential GDP: quarterly data. Period: 1987:3-2004:3. Source: U.S. Congress, Congressional Budget Office.

Price level index:

- U.S. implicit price deflator of GDP: quarterly, seasonally adjusted data. Period: 1987:3-2004:3. Source: U.S. Department of Commerce, Bureau of Economic Analysis.

Interest rates:

- Federal funds rate: quarterly data. Period: 1987:3-2004:3. Source: Board of Governors of the Federal Reserve System.
- 1-Year Treasury Constant Maturity Rate: quarterly data. Period: 1994:1-2004:3. Source: Board of Governors of the Federal Reserve System.

References

[1] Amato, Jeffrey D., and Thomas Laubach (2003) "Estimation and control of an optimization-based model with sticky prices and wages," *Journal of Economic Dynamics and Control* 27, 1181-1215.

[2] Ang, Andrew, and Monika Piazzesi (2003) "A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables," *Journal of Monetary Economics* 50, 745-787.

[3] Ang, Andrew, Sen Dong, and Monika Piazzesi (2005) “No-arbitrage Taylor rules,” Columbia University and University of Chicago, mimeo.

[4] Boivin, Jean, and Marc P. Giannoni (2003) “Has monetary policy become more effective?,” Columbia University mimeo.

[5] Bekaert, Geert, Seonghoon Cho, and Antonio Moreno (2005) “New-Keynesian macroeconomics and the term structure,” Columbia University mimeo.

[6] Calvo, Guillermo (1983) “Staggered prices in a utility-maximizing framework,” *Journal of Monetary Economics* 12, 383-398.

[7] Carey, Kevin (2001) “Testing for stabilizing monetary policy rules: How robust to alternative specifications?, *Topics in Macroeconomics* 1 (1), Article 3

[8] Clarida, Richard, Jordi Galí, and Mark Gertler (1999) “The science of monetary policy: A New Keynesian perspective,” *Journal of Economic Literature* 37, 1661-1707.

[9] Clarida, Richard, Jordi Galí, and Mark Gertler (2000) “Monetary policy rules and macroeconomic stability: evidence and some theory,” *Quarterly Journal of Economics* 115, 147-180.

[10] Cochrane, John H. (2001) *Asset Pricing*, Princeton University Press, Princeton.

[11] Cogley, Timothy, and Thomas J. Sargent (2002) “Drifts in volatilities: Monetary policies and outcomes in the Post WWII U.S.,” Arizona State University, mimeo.

[12] Cooley, Thomas F., and Lee E. Ohanian (1991) “The cyclical behavior of prices,” *Journal of Monetary Economics* 28, 25-60.

[13] Den Haan, Wouter J. (2000) “The comovement between output and prices,” *Journal of Monetary Economics* 46, 3-30.

[14] Diebold, Francis X., Glenn D. Rudebusch, and S. Boragan Aruoba (2004) “The macroeconomy and the yield curve: a dynamic latent factor approach,” *Journal of Econometrics* (forthcoming).

[15] Duffie, Darrell, and Kenneth J. Singleton (1993) “Simulated moments estimation of Markov models of asset prices,” *Econometrica* 61, 929-952.

[16] English, William B., William R. Nelson, and Brian P. Sack (2003) "Interpreting the significance of the lagged interest rate in estimated monetary policy rules," *Contributions to Macroeconomics* 3 (1) Article 5.

[17] Estrella, Arturo, and Gikas A. Hardouvelis (1991) "The term structure as a predictor of economic activity, *Journal of Finance* 46, 555-576.

[18] Estrella, Arturo, and Frederic S. Mishkin (1997) "The predictive power of the term structure of interest rates in Europe and the United States: Implications for the European Central Bank, *European Economic Review* 41, 1375-1401.

[19] Fama, Eugene F. (1990) "Term Structure Forecast of Interest Rates, Inflation and Real Returns," *Journal of Monetary Economics* 25, 59-76.

[20] Fuhrer, Jeffrey C. (2000) "Habit formation in consumption and its implications for monetary policy models," *American Economic Review* 90, 367-390.

[21] Galí, Jordi (2002) "New perspectives on monetary policy, inflation and the business cycle," National Bureau of Economic Research Working Paper 8767.

[22] Galí, Jordi, and Mark Gertler (1999) "Inflation dynamics: a structural econometric analysis," *Journal of Monetary Economics* 44, 195-222.

[23] Gallant, A. Ronald, and George Tauchen (1996) "Which moments to match?" *Econometric Theory* 12, 657-681.

[24] Gallant, A. Ronald, David Hsieh, and George Tauchen (1997) "Estimation of stochastic volatility models with diagnostics," *Journal of Econometrics* 81, 159-192.

[25] Gerlach-Kristen, Petra (2004) "Interest-rate smoothing: monetary policy or unobserved variables?" *Contributions to Macroeconomics* 4 (1) Article 3.

[26] Goodfriend, Marvin (1991)."Interest Rates and the Conduct of Monetary Policy", *Carnegie-Rochester Conference Series on Public Policy* 24, 231-274.

[27] Gouriéroux, Christian, and Alain Monfort, (1996) *Simulation-Based Econometric Methods.* Oxford University Press, Oxford.

[28] Gouriéroux, Christian, Alain Monfort, and Eric Renault (1993) "Indirect inference," *Journal of Applied Econometrics* 8, s85-s118.

[29] Gouriéroux, Christian, Eric Renault and Nizar Touzi (2000) "Calibration by simulation for small sample bias correction," in Mariano, R., T. Schuermann and M. Weeks (eds.) *Simulation-Based Inference in Econometrics, Methods and Applications.* Cambridge University Press, Cambridge.

[30] Gutiérrez, María-José, and Jesús Vázquez (2004) "Switching equilibria. The present value model for stock prices revisited," *Journal of Economic Dynamics and Control* 28, 2297-2325.

[31] Hördahl, Peter, Oreste Tristani and David Vestin (2004) "A joint econometric model of macroeconomic and term structure dynamics," European central Bank working paper series n^o 405. *Journal of Econometrics* (forthcoming).

[32] Kydland, Finn E., and Edward. C. Prescott (1990) "Business cycles: real facts and a monetary myth," Federal Reserve Bank of Minneapolis *Quarterly Review* 14, 3-18.

[33] Lee, Bong-Soo, Beth F. Ingram (1991) "Simulation estimation of time-series models," *Journal of Econometrics* 47, 197-205.

[34] Lowe, P. and Ellis, L. (1997) "The smoothing of official interest rates" in Lowe, P.(ed.) *Monetary Policy and Inflation Targeting Proceedings of a Conference*, Reserve Bank of Australia.

[35] Lubik, Thomas A., and Frank Schorfheide (2003) "Computing sunspot equilibria in linear rational expectations models," *Journal of Economic Dynamics and Control* 28, 273-285.

[36] Lubik, Thomas A., and Frank Schorfheide (2004) "Testing for indeterminacy: an application to U.S. monetary policy," *American Economic Review* 94, 190-217.

[37] Lubik, Thomas A., and Frank Schorfheide (2005) "Do central banks respond to exchange rate movements? A structural investigation," John Hopkins University and University of Pennsylvania working paper.

[38] Mankiw, N. Gregory (2001) "The inexorable and mysterious trade-off between inflation and unemployment," *Economic Journal* 111, C45-61.

[39] María-Dolores, Ramón, and Jesús Vázquez (2004) "The New Keynesian monetary model: Does it show the comovement between output and inflation in the US?" Universidad del País Vasco, mimeo. Paper presented at the ESWC2005 (London) and the 20th Congress of the EEA (Amsterdam).

[40] María-Dolores, Ramón, and Jesús Vázquez (2005) "How the New Keynesian monetary model fit in the US and the Euro area? An indirect inference approach" Universidad del País Vasco, mimeo.

[41] Mishkin, Frederick S. (1990) The information in the longer maturity term structure about future inflation, *Quarterly Journal of Economics* 105, 815-828.

[42] Rudebusch, Glenn D. (2002) "Term structure evidence on interest rate smoothing and monetary policy inertia," *Journal of Monetary Economics* 49, 1161-1187.

[43] Rudebusch, Glenn D., and Tao Wu (2004) "A macro-finance model of the term structure, monetary policy and the economy," *Federal Reserve Bank of San Francisco*, Working Paper 2003-17.

[44] Ruge-Murcia, Francisco (2003) "Methods to estimate dynamic stochastic general equilibrium models," University of Montreal and CIREQ working paper n^o 17.

[45] Sack, Brian (1997) "Uncertainty and gradual monetary policy," *Federal Reserve Board,* mimeo.

[46] Sims, Christopher A. (2002) "Solving linear rational expectations models," *Computational Economics* 20, 1-20.

[47] Sims, Christopher A., and Tao Zha (2004) "Were there regime switches in U.S. monetary policy?," Princeton University, mimeo.

[48] Smith, Anthony A. (1993) "Estimating nonlinear time-series models using simulated vector autoregressions", *Journal of Applied Econometrics* 8, s63-s84.

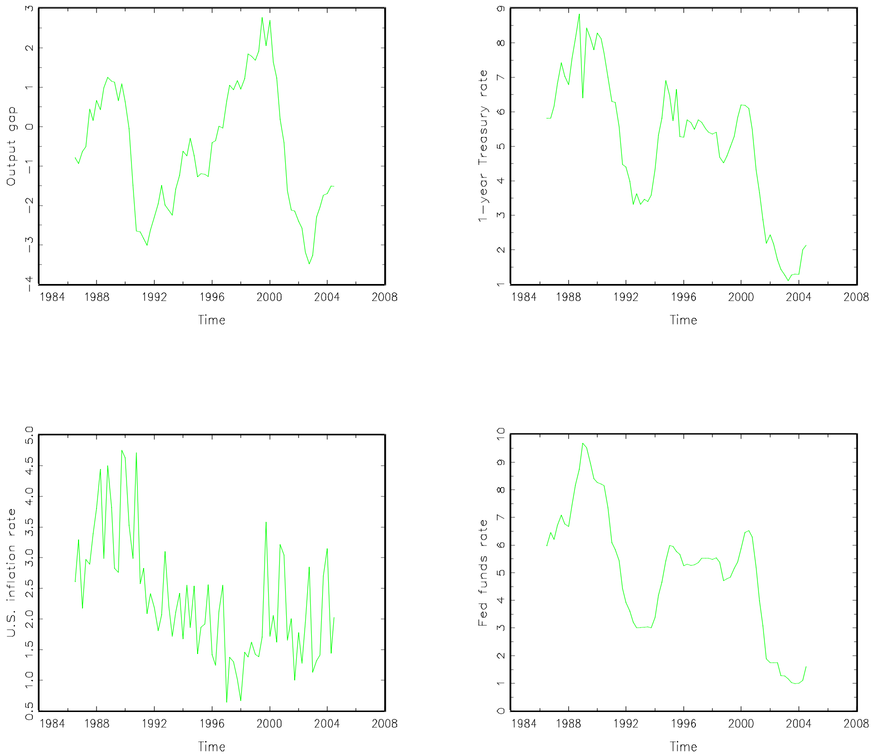

Figure 1: Time series plots

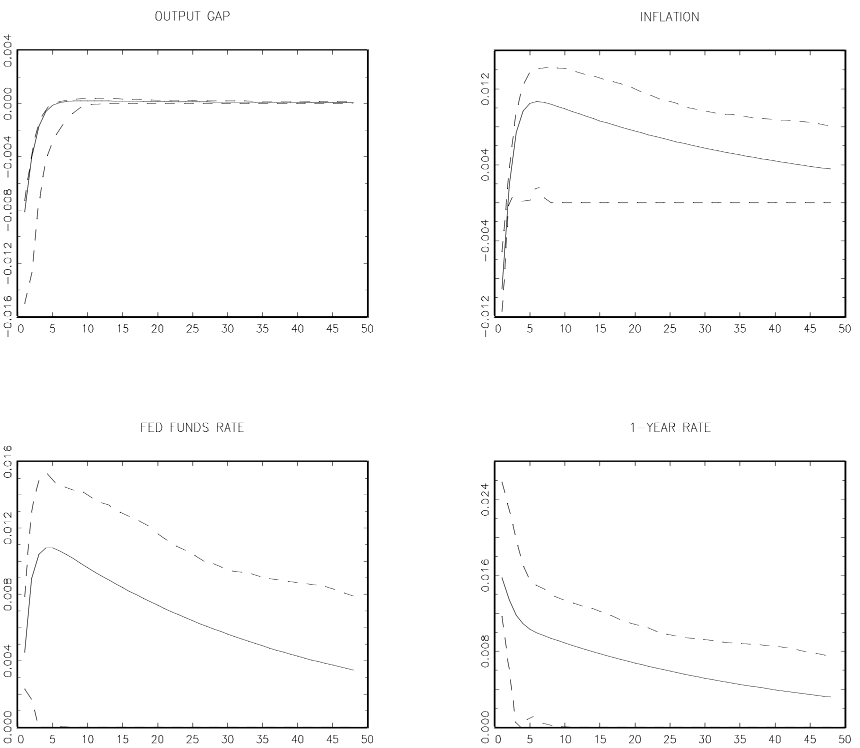

Figure 2: Response to a contractionary monetary policy shock

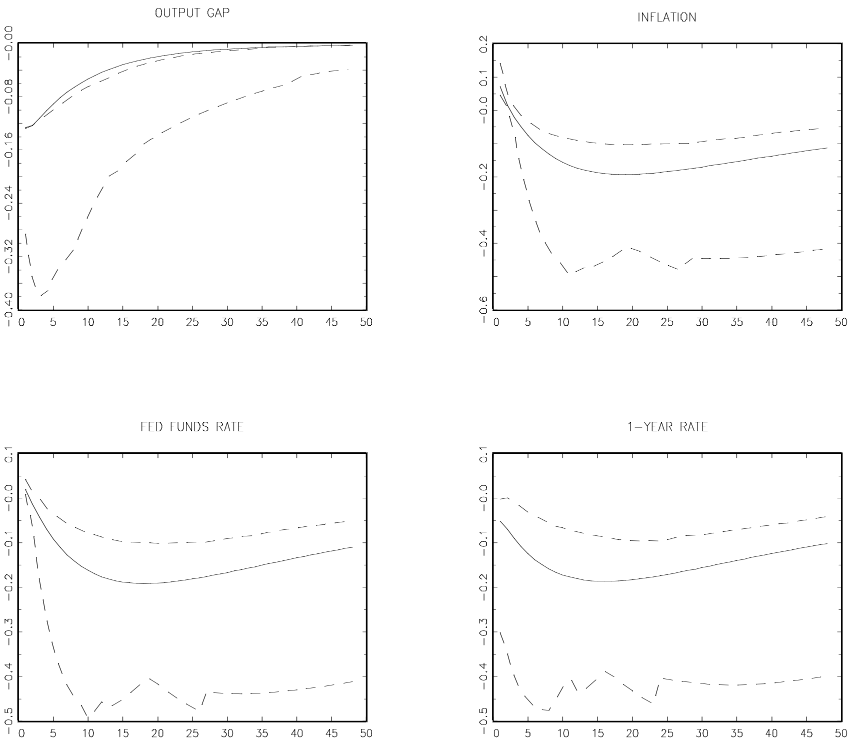

Figure 3: Response to a contractionary AS shock

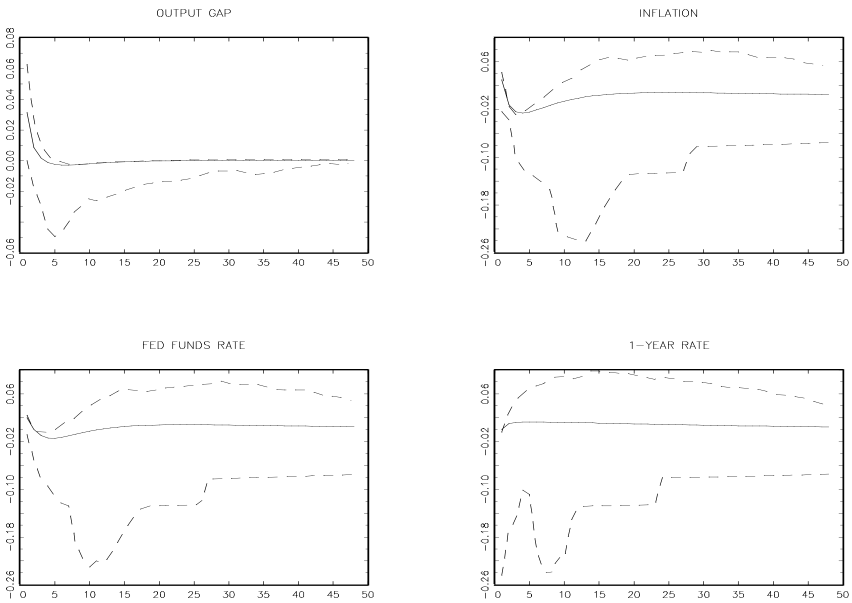

Figure 4: Response to a positive AD shock

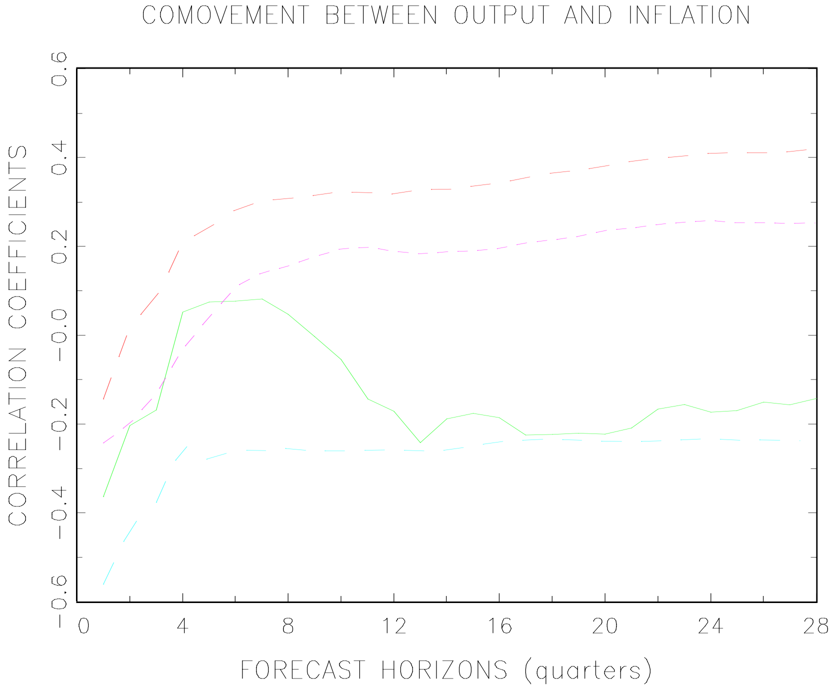

Figure 5: Comovement between output and inflation

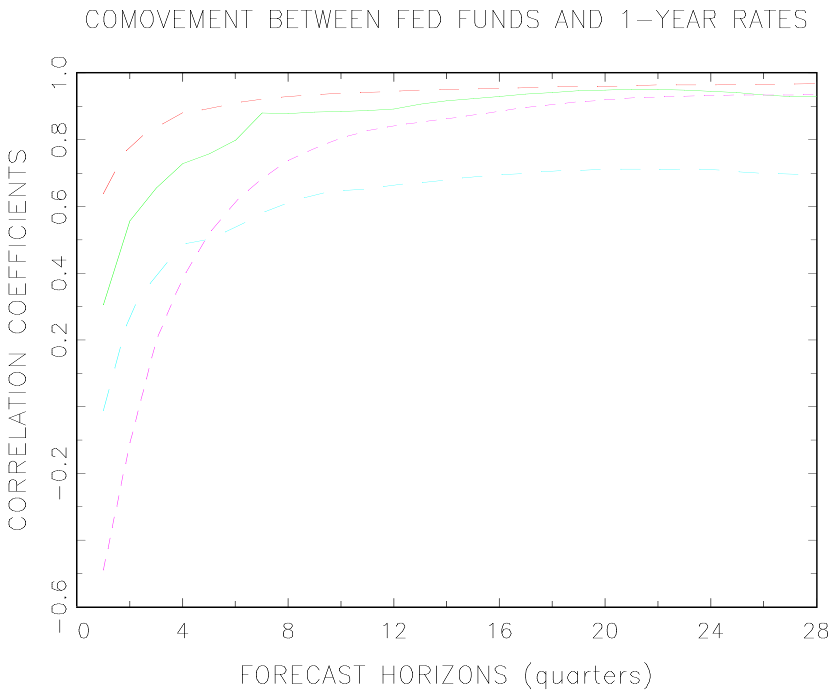

Figure 6: Comovement between the Fed funds and the 1-year rates

Table 1. Estimation results of the NKM model with term structure and standard Taylor (3)

		$\psi_3 = 0$	$\rho_v = 0$	Current spread
J_T	2.5959	2.9107	3.1075	2.6801
τ	0.9937	0.9946	0.9932	0.9944
	(0.3414)	(0.2896)	(0.1705)	(0.2978)
β	0.9983	0.9970	0.9925	0.9979
	(0.0009)	(0.0012)	(0.0007)	(0.0011)
ρ	0.5611	0.3553	0.7537	0.4022
	(0.0910)	(0.1205)	(0.0495)	(0.0963)
κ	0.9918	0.9932	0.9909	0.9926
	(0.3956)	(0.4138)	(0.2032)	(0.4643)
ψ_1	0.9757	0.9180	0.7460	0.9828
	(0.0108)	(0.0313)	(0.0783)	(0.0164)
ψ_2	0.1917	0.1471	0.5033	0.1038
	(0.0657)	(0.0499)	(0.1035)	(0.0510)
ψ_3	0.4858		0.3300	0.4363
	(0.2056)		(0.3256)	(0.2008)
ρ_g	0.6724	0.5443	0.9676	0.6787
	(0.0702)	(0.1044)	(0.0561)	(0.0800)
$\rho_g^{\{4\}}$	0.8556	0.8656	0.9714	0.8456
	(0.0624)	(0.0498)	(0.0962)	(0.0680)
ρ_z	0.9125	0.9370	0.9172	0.9246
	(0.0213)	(0.0219)	(0.0194)	(0.0224)
ρ_v	0.3586	0.5620		0.5562
	(0.0995)	(0.0582)		(0.0633)
ρ_{gg}	0.9932	0.9924	0.9928	0.9930
	(0.2898)	(0.3628)	(0.8645)	(0.3811)
σ_g	0.0716	0.0585	0.0036	0.0734
	(0.0184)	(0.0183)	(0.0035)	(0.0190)
$\sigma_g^{\{4\}}$	0.0586	0.0712	0.0324	0.0425
	(0.0113)	(0.0136)	(0.0044)	(0.0199)
σ_z	0.2279	0.2333	0.1892	0.2449
	(0.0789)	(0.0934)	(0.0379)	(0.1068)
σ_ϵ	0.0103	0.0158	0.0014	0.0121
	(0.0117)	(0.0104)	(0.0028)	(0.0079)
π^*	0.4817	0.7451	2.2438	0.5743
	(0.2681)	(0.2925)	(0.1987)	(0.3033)

Note: Standard errors in parentheses.

Table 2. Estimation results of NKM model with term structure and forward-looking Taylor rule (8)

		$\psi_3 = 0$	$\rho_v = 0$	Current spread
J_T	2.9846	2.9866	3.1553	3.0843
τ	0.9931	0.9931	0.9932	0.9943
	(0.1959)	(0.1898)	(0.1291)	(0.2613)
β	0.9923	0.9923	0.9927	0.9976
	(0.0007)	(0.0007)	(0.0008)	(0.0010)
ρ	0.4076	0.3867	0.5473	0.8049
	(0.0793)	(0.0620)	(0.0562)	(0.1798)
κ	0.9906	0.9906	0.9908	0.9931
	(0.2786)	(0.2839)	(0.2248)	(0.2651)
ψ_1	0.9300	0.9243	0.9363	0.9524
	(0.0306)	(0.0272)	(0.0337)	(0.0520)
ψ_2	0.0371	0.0382	0.1035	1.5944
	(0.0181)	(0.0176)	(0.0449)	(2.1022)
ψ_3	0.0317		0.1750	0.0000
	(0.0918)		(0.0987)	(0.2082)
ρ_g	0.5996	0.6052	0.5961	0.9246
	(0.0956)	(0.0915)	(0.7117)	(0.0425)
$\rho_g^{\{4\}}$	0.7227	0.7228	0.9567	0.9763
	(0.0660)	(0.0711)	(0.0616)	(0.0177)
ρ_z	0.9598	0.9601	0.9299	0.8827
	(0.0111)	(0.0109)	(0.0184)	(0.0229)
ρ_v	0.4462	0.4740		0.5079
	(0.0949)	(0.0648)		(0.0715)
ρ_{gg}	0.9928	0.9928	0.9928	0.9938
	(0.5102)	(0.5238)	(1.8117)	(0.4115)
σ_g	0.0213	0.0211	0.0027	0.0044
	(0.0112)	(0.0108)	(0.0038)	(0.0022)
$\sigma_g^{\{4\}}$	0.0183	0.0182	0.0235	0.0250
	(0.0029)	(0.0030)	(0.0031)	(0.0084)
σ_z	0.19870	0.20136	0.17404	0.08327
	(0.0657)	(0.0676)	(0.0404)	(0.0184)
σ_ϵ	0.0071	0.0075	0.0012	0.0000
	(0.0030)	(0.0030)	(0.0028)	(0.0019)
π^*	2.34950	2.35370	2.15510	0.68060
	(0.2613)	(0.2642)	(0.2321)	(0.2802)

Note: Standard errors in parentheses.

Table 3. Estimation results of NKM model with term structure and backward-looking Taylor rule (9)

		$\psi_3 = 0$	$\rho_v = 0$	Current spread
J_T	2.8294	2.8893	3.1476	2.8893
τ	0.9996	0.9964	0.9999	0.9964
	(0.3166)	(0.2802)	(0.1552)	(0.2912)
β	0.9982	0.9973	0.9929	0.9973
	(0.0007)	(0.0010)	(0.0008)	(0.0010)
ρ	0.7512	0.8350	0.8387	0.8350
	(0.0826)	(0.0987)	(0.0802)	(0.1002)
κ	0.9438	0.9985	1.0000	0.9985
	(0.2317)	(0.2456)	(0.1916)	(0.2737)
ψ_1	0.6556	0.1296	0.68310	0.1296
	(0.1006)	(0.2889)	(0.3987)	(0.3100)
ψ_2	1.1129	1.7714	0.8854	1.7714
	(0.4092)	(1.1398)	(0.5628)	(1.1540)
ψ_3	0.9998		1.4007	0.0000
	(0.3311)		(0.7329)	(0.3659)
ρ_g	0.9762	0.9693	0.9684	0.9693
	(0.0112)	(0.0143)	(0.0309)	(0.0146)
$\rho_g^{\{4\}}$	0.9899	0.9910	0.9844	0.9910
	(0.0048)	(0.0046)	(0.0171)	(0.0046)
ρ_z	0.8817	0.9110	0.9100	0.9110
	(0.0385)	(0.0262)	(0.0255)	(0.0262)
ρ_v	0.3543	0.4462		0.4462
	(0.1326)	(0.1339)		(0.1358)
ρ_{gg}	0.9999	0.9971	0.9999	0.9971
	(0.1507)	(0.1419)	(0.38639)	(0.1454)
σ_g	0.0325	0.0253	0.0044	0.0253
	(0.0152)	(0.0111)	(0.0026)	(0.0116)
$\sigma_g^{\{4\}}$	0.0608	0.0514	0.0305	0.0514
	(0.0107)	(0.0085)	(0.0040)	(0.0099)
σ_z	0.2824	0.2923	0.1742	0.2923
	(0.0593)	(0.0680)	(0.0334)	(0.0714)
σ_ϵ	0.0120	0.0000	0.0008	0.0000
	(0.0063)	(0.0097)	(0.0009)	(0.0100)
π^*	0.2692	0.4284	2.1062	0.4284
	(0.1338)	(0.1876)	(0.2191)	(0.1898)

Note: Standard errors in parentheses.

Table 4. Estimation results of the NKM model with n=1 and m=100

	Standard	Forward-look	Backward-look	Current spread
J_T	3.1239	3.3414	3.8185	3.4405
τ	1.0000	1.0000	1.0000	0.9971
	(0.1719)	(0.2715)	(0.2432)	(0.1504)
β	0.9954	0.9940	0.9988	0.9953
	(0.0008)	(0.0011)	(0.0002)	(0.0008)
ρ	0.3953	0.4992	0.7925	0.6312
	(0.0799)	(0.0700)	(0.0434)	(0.0544)
κ	1.0000	1.0000	1.0000	0.9973
	(0.3138)	(0.3911)	(0.2142)	(0.2186)
ψ_1	0.9006	0.9892	0.7028	0.8484
	(0.0314)	(0.0105)	(0.0660)	(0.0837)
ψ_2	0.0842	0.0000	1.2186	0.3496
	(0.0164)	(0.0062)	(0.2113)	(0.1416)
ψ_3	0.0390	0.1145	1.0637	0.0000
	(0.0845)	(0.0872)	(0.3248)	(0.4698)
ρ_g	0.7411	0.7159	0.9408	0.8946
	(0.0746)	(0.0478)	(0.0173)	(0.0616)
$\rho_g^{\{4\}}$	0.9682	0.7777	0.9170	0.9507
	(0.0192)	(0.0554)	(0.0266)	(0.0500)
ρ_z	0.9804	0.9822	0.9005	0.9385
	(0.0050)	(0.0066)	(0.0195)	(0.0156)
ρ_v	0.6743	0.6946	0.4339	0.2583
	(0.0538)	(0.0515)	(0.1027)	(0.0784)
ρ_{gg}	1.0000	1.0000	1.0000	0.9961
	(0.1889)	(0.1840)	(0.1323)	(0.3712)
σ_g	0.0137	0.0265	0.0607	0.0089
	(0.0035)	(0.0089)	(0.0252)	(0.0026)
$\sigma_g^{\{4\}}$	0.0307	0.0114	0.0586	0.0267
	(0.0040)	(0.0034)	(0.0081)	(0.0050)
σ_z	0.2438	0.1757	0.2499	0.2152
	(0.0900)	(0.0934)	(0.0441)	(0.0542)
σ_ϵ	0.0061	0.0099	0.0366	0.0051
	(0.0025)	(0.0042)	(0.0125)	(0.0022)
π^*	1.1100	1.5911	0.1817	1.3445
	(0.1979)	(0.3067)	(0.0336)	(0.2072)

Table 5. VAR estimates and diagnostic tests

Variable	Estimate	Standard error	Diag. stat. for (3)	Diag. stat. for (8)	Diag. stat. for (9)
	Output	**gap**	**equation**		
constant	0.081450	0.24292	0.44589	0.73065	0.44300
outputgap(1)	1.13403***	0.15121	1.59487	0.78879	0.85754
outputgap(2)	0.01556	0.21266	0.20661	0.41210	0.74737
outputgap(3)	−0.43313**	0.20519	−2.30888	−2.13297	−2.34313
outputgap(4)	0.09938	0.14841	0.60361	0.61018	0.51371
inflation(1)	0.04411	0.09145	−0.16722	−0.57633	0.33596
inflation(2)	−0.10954	0.08574	−0.41272	−1.07259	−1.14360
inflation(3)	−0.09446	0.09737	−0.98243	−1.26966	−1.06333
inflation(4)	−0.08307	0.09889	−1.25748	−0.91230	−1.08227
Fed rate(1)	0.291505	0.25601	1.59695	1.72040	1.07937
Fed rate(2)	−0.08858	0.34167	−0.63354	−0.46469	−0.18493
Fed rate(3)	0.11778	0.32782	0.58232	0.57433	0.46486
Fed rate(4)	−0.09673	0.17466	−0.67417	−0.79736	−0.77564
1-year rate(1)	−0.06454	0.12000	−1.43968	−1.50222	−1.08369
1-year rate(2)	0.02248	0.14641	0.64146	0.52151	0.58992
1-year rate(3)	−0.29845**	0.14641	−2.21393	−2.46649	−2.33959
1-year rate(4)	0.195724	0.15644	1.41180	1.57185	1.56781
	Inflation	**equation**			
constant	0.64491*	0.36181	2.19838	2.70936	2.28764
outputgap(1)	0.20367	0.22521	0.57191	0.67331	0.64803
outputgap(2)	−0.12120	0.31675	−0.44351	−0.30204	−0.26653
outputgap(3)	0.14103	0.30561	0.74774	0.18475	0.50323
outputgap(4)	−0.18291	0.22105	−0.85322	−0.20463	−0.54400
inflation(1)	0.19503	0.13621	−3.05449	−2.29684	−3.66787
inflation(2)	0.09031	0.12770	0.64107	1.08717	0.60195
inflation(3)	0.17990	0.14502	1.38965	1.31617	0.21443
inflation(4)	0.41321***	0.14729	3.36270	3.52824	3.82600
Fed rate(1)	−0.39995	0.38131	−1.98112	−1.78725	−1.66116
Fed rate(2)	0.34854	0.50889	1.00360	0.80288	0.76405
Fed rate(3)	0.53918	0.48826	1.28200	1.22098	1.39985
Fed rate(4)	−0.20357	0.26014	−0.79122	−0.70195	−0.72646
1-year rate(1)	0.22395	0.17873	0.89156	0.74251	0.81751
1-year rate(2)	0.10468	0.21807	0.52155	0.52850	0.72424
1-year rate(3)	−0.35473	0.21807	−1.86743	−1.92442	−1.95681
1-year rate(4)	−0.31689	0.23300	−1.44574	−1.58472	−1.37198

Table 5. (Continued)

Variable	Estimate	Standard error	Diag. stat. for (3)	Diag. stat. for (8)	Diag. stat. for (9)
	Fed funds	**rate**	**equation**		
constant	−0.09659	0.12861	−0.93639	−0.14060	−0.99298
outputgap(1)	0.31942***	0.08005	1.99824	1.30827	1.06253
outputgap(2)	−0.05555	0.11259	−0.16552	−0.18860	0.52460
outputgap(3)	−0.07561	0.10863	−0.58157	−0.42524	−0.48226
outputgap(4)	−0.03052	0.07857	0.08345	0.55791	−0.08729
inflation(1)	0.03523	0.04842	0.04184	−0.49885	0.78292
inflation(2)	0.14275**	0.04539	−0.32401	−0.37637	0.45391
inflation(3)	0.05327	0.05155	1.18351	1.98123	0.03232
inflation(4)	0.04727	0.05235	1.01738	0.74852	3.52028
Fed rate(1)	0.97088***	0.13554	−0.73394	−0.63721	−0.75215
Fed rate(2)	−0.64342***	0.18089	−2.25276	−1.74868	−2.48988
Fed rate(3)	0.37923**	0.17355	2.37983	2.45563	2.63725
Fed rate(4)	−0.22931**	0.09247	−2.19375	−2.31232	−2.88810
1-year rate(1)	0.29229***	0.06353	0.42519	1.80033	2.01406
1-year rate(2)	0.05208	0.07751	1.35846	−0.39948	−0.15196
1-year rate(3)	0.10992	0.07751	1.60699	1.90575	1.71270
1-year rate(4)	−0.03902	0.08282	0.08581	−1.00187	0.26401
	1-year	**rate**	**equation**		
constant	0.23396	0.29469	0.71146	−1.25502	0.38178
outputgap(1)	0.35880*	0.18343	1.15968	0.01260	1.07386
outputgap(2)	−0.10878	0.25798	−0.26728	0.74966	−0.39736
outputgap(3)	−0.04059	0.24892	−0.72260	0.78294	−0.17197
outputgap(4)	−0.12736	0.18004	−0.71983	−1.88874	−1.27196
inflation(1)	−0.02604	0.11094	−1.48077	−1.77168	−1.22227
inflation(2)	0.21906**	0.10401	−0.76173	1.75857	0.33738
inflation(3)	−0.01992	0.11812	0.19738	0.67749	−0.74554
inflation(4)	0.01583	0.11997	−0.00385	−0.87021	−0.28770
Fed rate(1)	0.49114	0.31057	1.66141	0.68605	1.83429
Fed rate(2)	−0.76472*	0.41449	−1.26136	−0.55308	−1.11289
Fed rate(3)	0.46950	0.39768	1.28338	1.51689	1.42875
Fed rate(4)	−0.12385	0.21188	−0.44589	−0.53957	−0.77117
1-year rate(1)	0.59354***	0.14557	−2.56420	0.91261	−1.93877
1-year rate(2)	0.20563	0.17761	1.07408	0.18512	0.19927
1-year rate(3)	0.22268	0.17762	0.78056	1.42834	0.86502
1-year rate(4)	−0.22513	0.18978	−1.55475	−2.11129	−1.75388

Table 5. (Continued)

Variable	Estimate	Standard error	Diag. stat. for (3)	Diag. stat. for (8)	Diag. stat. for (9)
	VAR residuals	variance	matrix		
s11	0.16765	0.23709	4.88828	5.33677	5.22570
s21	−0.08010	0.26223	−2.43836	−1.74392	−2.32153
s31	0.02270	0.09161	2.94185	3.68503	2.76910
s41	0.04903	0.20920	2.38349	1.26924	0.88244
s22	0.37190	0.52594	5.61964	5.16367	5.81972
s23	−0.00545	0.13230	−1.57128	−1.44254	−0.64903
s24	−0.01403	0.30323	0.95577	1.76615	0.97168
s33	0.04699	0.06645	0.33517	1.18831	0.55761
s34	0.03480	0.11315	0.08394	−0.61637	−1.02016
s44	0.24671	0.34891	0.85427	0.53449	−0.12236

Note: ***,**,* denote that the corresponding coefficients are statistically significant at the 1%, 5% and 10% levels, respectively.